Acoustic Characterization of Suspended Sediment Plumes Resulting from Barge Overflow

PURPOSE: This technical note presents the results of acoustic monitoring of suspended sediment plumes resulting from overflow from hydraulically filled barges during dredging operations in the Cape Fear River, North Carolina. Acoustic monitoring was used to characterize the spatial extent, concentration gradient structure, and dynamics of plumes during flood and ebb tidal stages.

BACKGROUND: During all dredging and dredged material disposal operations, some sediment is resuspended into the water column. Suspended sediments and their subsequent deposition are sources of concern to fishery resource agencies due to potential impacts on sensitive biological species and their habitats. A review of suspended sediment effects in coastal habitats with an emphasis on potential impacts of dredging operations can be found in Clarke and Wilber (2000) and Wilber and Clarke (2001). Although hydraulic cutterhead dredges generally produce small plumes that decay rapidly, operations involving overflow from hydraulically filled barges can introduce much greater quantities of sediment into the water column. Hence, concerns for fish spawning and nursery habitat in the vicinity of dredging operations in the Cape Fear River, North Carolina, have been raised. Precautionary monitoring of suspended sediment plumes generated by barge overflow was undertaken to determine the spatial extent of the waterway affected by the plumes and any resultant increase in suspended sediment concentration over ambient conditions. To avoid impacts to fishery habitat, a consensus had been reached that suspended sediment plumes should be restricted to within 273 m of the center line of the main navigation channel. Thus monitoring was designed to determine if plumes extended outside this buffer zone.

Because plumes, driven by tidal forces, change dynamically over large spatial scales and short time scales, characterizing plumes has presented severe challenges to many monitoring efforts. Data collected at points in time at fixed locations are generally insufficient to rigorously assess the potential effects of dredging. Acoustic surveys offer advantages in capturing data at appropriate spatial and temporal scales to allow accurate interpretation of plume dynamics. Therefore acoustic Doppler current profiler (ADCP) technology was employed to characterize the plumes created by the hydraulic cutterhead dredge *Texas*, which was configured to pump to a spider barge for placement in transport barges. In brief, the ADCP measures current velocities and direction by tracking acoustic energy returned from suspended particles being carried by water currents. This energy, or backscatter, can be used to derive estimates of suspended sediment concentration. Thus, in the present study the major objective was to track and map plumes emanating from the dredging operations, including barge overflow. Note that "overflow" is a generic term. The supernatant discharge from the barges in this project actually occurred through the bottom of the barge rather than over the gunnels or weir.

STUDY AREA: The plume characterization study was conducted in the Cape Fear River, North Carolina. The study area is depicted in Figure 1, which represents a portion of National Oceanic and Atmospheric Administration nautical chart 11537 at approximately 34°07.80 N and

77°65.40 W. Ebb tide and ambient survey transects were located just east of Campbell Island covering a portion of the Keg Island Range. Flood tide transects began slightly north of Campbell Island extending to the southern portion of the Big Lower Range.

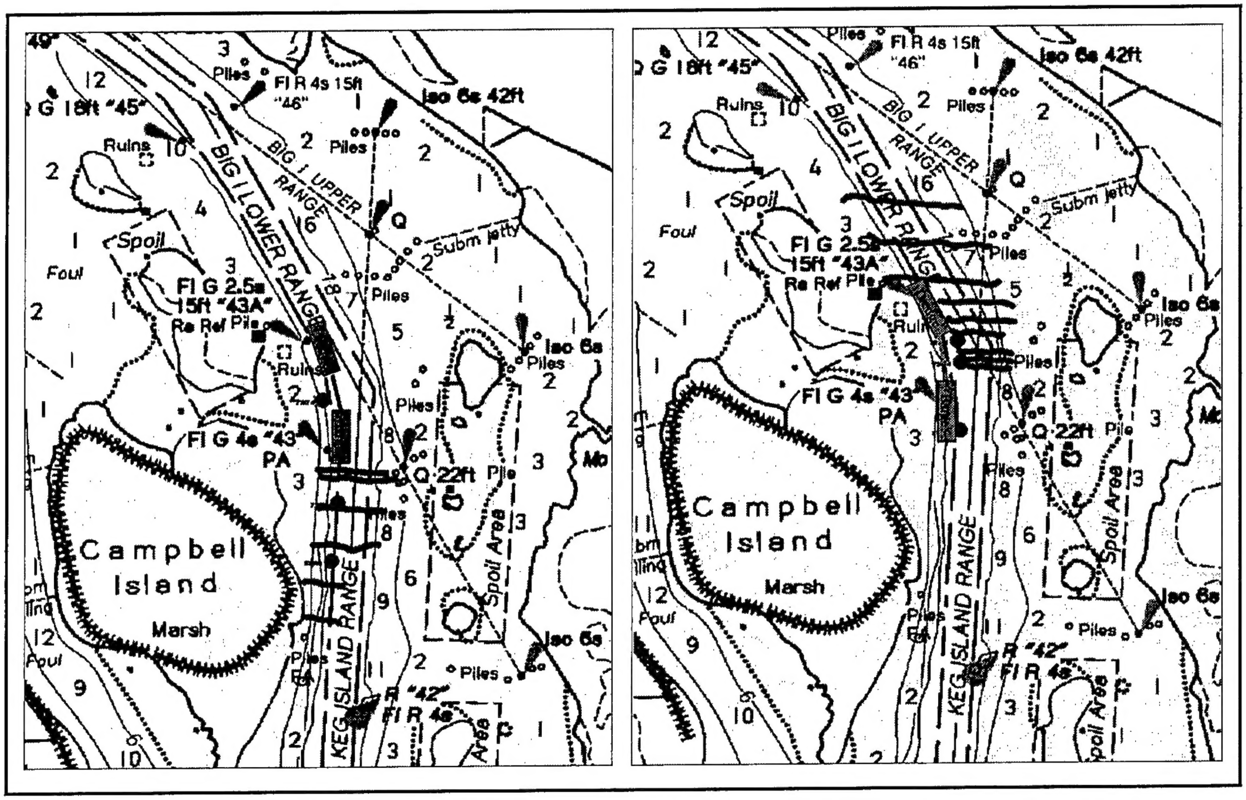

Figure 1. Location of ebb (left) and flood (right) tide transects (red) and optical backscatter sensor units (blue) in relation to dredging operations in the Cape Fear River, North Carolina

METHODS

Survey Design

Ebb tide survey: The ebb tide survey was completed on 3 December 2001. Six transects extended laterally across the river cross section covering the full extent of the plume where possible (due to pipeline position and other barriers) and terminating where water depth over the shoals adjacent to the navigation channel became too shallow (<1 m) to be surveyed. The first transect was located just south of channel marker 43. Subsequent transects extended southward covering a portion of the Keg Island Range (Figure 1). Downstream extent of the survey was based on the observed decay of the plume in comparison with ambient conditions. Transects 1 and 2 were located 30 and 60 m, respectively, from the barge overflow. Transect 3 was located 152 m from the barge overflow, and ensuing transects were run at approximately 152-m increments. Distances for subsequent transects (4 through 6) downstream from the discharge point were 303, 455, and 606 m, respectively. Transects 5 and 6 were necessarily shortened due to passing ship traffic. Length of transects ranged from 132 to 298 m (mean = 230 m).

Flood tide survey: The flood tide survey was completed on 4 December 2001. Following a protocol similar to that used in the ebb tide survey, 9 cross-section transects were occupied, extending from the spider barge overflow (north of channel marker 43) upstream along the Big Lower Range (Figure 1). Transect 1 was located 10 m from the spider barge. Subsequent transects ran in sequence upstream in the direction of plume movement. Transects 2 and 3 were located 30 and 60 m from Transect 1. Distances upstream for Transects 3 through 7 increased by approximately 76-m increments such that Transect 7 was located 374 m from the spider barge discharge. Beyond this point, the distance between transects increased to 152 m so that Transects 8 and 9 were located 526 and 678 m, respectively, from the spider barge. Note that Transects 1-6 did not extend the full width of the channel due to the position of the dredge pipeline in the survey area. Transect length ranged from 200 to 481 m (mean = 309 m).

Ambient survey: The ambient survey was completed on 4 December 2001. Eight transects were established between channel marker 43A and a point just south of channel marker 43. The survey was conducted during flood tide conditions on the downstream side of the dredging operation. With a flooding tide, this area would not be in the direction of plume movement. Transect 1 was established just off the spider barge at a distance of approximately 10 m. Transects 2 and 3 were occupied at ranges of 30 and 60 m, respectively. For Transects 4-6 the distances from the barge increased to 291 m (Transect 6) in 76-m increments, and for Transects 7 and 8 the distance increased to 595 m in 152-m increments. Transect lengths ranged from 302 to 353 m (mean = 317 m).

Data Collection and Processing. An RD Instruments 600-KHz Mariner Workhorse® Series ADCP was used to collect current velocity, direction, and backscatter data. RD Instruments WinRiver® software running on a laptop computer was used for both data collection and display. WinRiver® software determines and records current velocity and direction in predetermined vertical bins along each transect surveyed. Vessel direction and speed and current velocity in three directional axes (manufacturer's stated accuracy of ±0.2 cm/sec) at selected collection data ranges, bottom depth, and surface water temperatures were recorded. An internal fluxgate compass allowed the instrument to correct ADCP current velocity and direction regardless of vessel speed or orientation. A specific serial file name was created by the acquisition software for each transect surveyed, and data were stored in a binary raw data file. Data collection parameters were entered and stored in a configuration file. A third file, consisting of navigation data received from an external Global Positioning System, was also collected and used in data post-processing. ADCP raw backscatter data were analyzed using Sediview Software provided by Dredging Research LTD. The Sediview Method (Land and Bray 2000) derives estimates of suspended solids concentration throughout the water column based on acoustic backscatter data obtained by the ADCP.

Calibration. In order to convert backscatter data (decibel units) to suspended sediment concentration (mg/L), the ADCP data must first be calibrated against known concentrations. To accomplish this step, water samples were collected at specific locations within the ADCP beam at several stations exhibiting a range in concentration. The water samples were analyzed gravimetrically using standard methods. Water sample total suspended solids (TSS) concentrations were then matched to an exact acoustic ping number in the corresponding ADCP data file. Therefore, for each ADCP calibration file there is a corresponding water sample of a known TSS concentration. Both temperature and salinity profiles are collected and stored in the Sediview calibration file. These measurements are needed to make accurate corrections for acoustic energy absorption in water.

Differences between known and estimated sediment concentrations are then examined and corrected in the Sediview data analysis program. The calibration results, from which Sediview derived estimates of TSS concentration, are compared to the observed values based on TSS gravimetric analyses. A relatively close correspondence was found for these Cape Fear River data, with the exception of several data pairs where the Sediview estimate greatly exceeded the water sample concentration. These discrepancies are very likely due to air bubbles entrained in the overflow plume close to the discharge location. This effect has been observed in other Sediview applications, and is generally limited to the near-field plume. With increasing distance (time) from the source, the air bubbles dissipate and the error factor is minimized.

Optical Backscatter Sensor (OBS) Deployment. Optical backscatter sensors (OBS) equipped with data loggers were deployed to measure turbidity levels (nephelometric turbidity units (NTU)) throughout the tidal cycle during each ADCP survey. OBS units work by projecting a beam of light into a volume of water and measuring the amount of light scattered out of the beam. Representing a fixed location, the processed data can be examined for evidence of a plume "signature" against background as the plume is carried by tidal currents through that location. Optical and other physical monitoring methodologies are reviewed by Puckette (1998). Three stations were chosen near the point of discharge. Two stations (one near-field, one far-field) were positioned in the direction of plume movement. The third station was located upcurrent from the dredging operation in order to measure ambient conditions. Each station consisted of two OBS units tethered to a buoy and anchor system at depths of 1.5 and 7.5 m. A total of six OBS units were deployed. NTU values for upstream and downstream deployments (OBS units deployed closest to the spider barge are labeled near-plume) of OBS units during both ebb and flood tides can be found in Tables 1 and 2, respectively.

Table 1
NTU Values for Upsteam-Downstream Deployment of OBS Units During Ebb Tide

Station	Location from Barge	Measurement	Depth m	NTU Mean	NTU Range
1	Downstream	Near Plume	1.5	24.3	9.9-87.0
			7.5	23.2	12.8-39.9
2	Downstream	Far Plume	1.5	20.1	10.6-53.9
			7.5	30.4	19.3-70.0
3	Upstream	Ambient	1.5	18.3	9.8-36.5
			7.5	21.1	10.9-35.0

Table 2
NTU Values for Upsteam-Downstream Deployment of OBS Units During Flood Tide

Station	Location from Barge	Measurement	Depth m	NTU Mean	NTU Range
1	Upstream	Near Plume	1.5	18.1	7.5-106.4
			7.5	38.9	9.0-126
2	Upstream	Far Plume	1.5	13.3	7.0-47.7
			7.5	29.8	8.7-93.6
3	Downstream	Ambient	1.5	12.5	7.8-43.1
			7.5	45.3	13.9-127.7

Total Suspended Solids. Several presurvey ADCP transects were run to determine the upstream or downstream (depending on tidal cycle) extent of the plume. The plume was divided into three regions, which included near field, midfield, and far field, corresponding to their proximity to the spider barge. Highest TSS concentrations were expected in the area nearest the spider barge discharge. Water samples were taken in an area outside of the plume boundaries (ambient conditions) and from shoals representing the fishery habitat of concern. This was accomplished by taking 1.0-L water samples using a Van Dorn style (Wildco Model) sampler. Water samples were collected at predetermined depths to adequately sample the entire water column. Water samples were iced and kept between 1 and 2 °C as required before processing. TSS samples were processed by Environmental Chemist, Inc., Wilmington, NC. Concentrations were measured to an accuracy of 1.0 mg/L.

Water Quality. Water quality data were collected using a Hydrolab® unit to record depth (m), temperature (°C), and salinity (ppt). Vertical profiles of the water column were taken in 2-m-depth increments from bottom to surface and examined for evidence of stratification. Salinity and temperature profiles were needed to make accurate corrections for the acoustic absorption properties of water in support of the ADCP backscatter calibration process. Water temperature and salinity differences of 1 °C and 2 ppt must be known in order to avoid errors in suspended sediment concentration estimates.

RESULTS

Total Suspended Solids. During ebb tide conditions, 28 water samples were collected at stations randomly dispersed between channel markers 42 and 43 of the Keg Island Range. TSS concentration ranged from 18 to 145 mg/L (mean = 52.5 mg/L). An additional 34 water samples were taken during flood tide between channel markers 43 and 43A. TSS concentration ranged from 18 to 191 mg/L (mean = 48.9 mg/L). Highest concentrations (maximum = 191 mg/L) were found near the spider barge overflow (e.g., flood tide samples 35-37). TSS concentrations for water samples taken over the shoals (protected fishery habitat) during active dredging ranged from 19 to 33 mg/L. Summaries of TSS concentrations for various depths throughout the water column during ebb (Samples 1-28) and flood (Samples 29-62) tides can be found in Table 3.

Water Quality. There was no evidence of a thermocline in the study area as water temperature varied little from bottom to surface. During ebb tide, water temperatures ranged from 17.6 to 17.9 °C (mean = 17.8). No substantive changes were observed during flood tide as water temperature ranged from 17.0 to 17.5 °C (mean = 17.3).

Salinity during an ebbing tide ranged from 18.4 to 25.9 ppt (mean = 21.1). Mean salinity (24.3 ppt) increased during flood tide; however, the range (20.6-27.7 ppt) did not vary markedly from that seen during ebb tide. Salinity values tended to be somewhat higher in surface waters and decreased gradually with depth. This pattern is reversed from expected salt-wedge circulation patterns, but may simply reflect mixing in this reach of the Cape Fear River. Surface to bottom salinity measurements usually differed by no more than 4 ppt.

Table 3
Gravimetric Analysis of Suspended Sediment Concentration in the Cape Fear River, North Carolina

Sample No.	Sample Location		Depth m	TTS Value mg/L	Sample No.	Sample Location		Depth m	TTS Value mg/L
	Latitude	Longitude				Latitude	Longitude		
1	340738	775615	1.5	145	32	347600	775617	9.9	39
2	*	*	4.0	82	33	347630	775617	4.9	18
3	*	*	5.5	93	34	347654	775618	2.3	24
4	*	*	6.0	102	35	347502	775614	1.3	191
5	347305	775619	1.6	43	36	347504	775614	1.3	104
6	347286	775614	2.0	71	37	347524	775614	1.2	177
7	347285	775615	6.1	134	38	347488	775614	9.6	66
8	347280	775615	9.7	98	39	347486	775614	4.2	27
9	347033	775619	4.6	62	40	347489	775614	1.4	151
10	346956	775615	4.7	27	41	347509	775615	9.3	61
11	346864	775616	10.1	31	42	347508	775616	4.5	40
12	347309	775616	10.1	78	43	347514	775615	2.4	36
13	347297	775616	5.7	39	44	347534	775617	6.9	28
14	347300	775616	1.1	28	45	347536	775617	5.1	40
15	347269	775616	10.4	51	46	347537	775616	2.4	34
16	347335	775618	2.2	24	47	347569	775616	7.2	28
17	347291	775617	4.6	32	48	347562	775616	5.6	25
18	347238	775618	6.0	31	49	347570	775616	1.5	23
19	347194	775619	2.0	33	50	347607	775617	9.4	61
20	347153	775617	10.1	53	51	347613	775617	5.6	60
21	347017	775618	5.0	25	52	347608	775617	2.6	24
22	346954	775619	2.3	20	53	347787	775646	2.0	24
23	347344	775615	10.1	35	54	347774	775637	1.7	33
24	347271	775615	6.1	31	55	347653	775630	1.5	21
25	347214	775615	2.4	18	56	347488	775621	1.9	19
26	347060	775618	10.2	37	57	347498	775615	3.9	33
27	346965	775620	5.0	27	58	347500	775615	3.6	47
28	346915	775621	1.8	21	59	347527	775615	2.5	20
29	347533	775614	9.3	24	60	347550	775615	3.9	26
30	347534	775614	5.2	32	61	347570	775616	3.1	23
31	347569	775616	2.0	22	62	347598	775616	10.1	82

Note: Samples 1-28 were taken during ebb tide, and Samples 29-62 were taken during flood tide.

Turbidity

Ebb tide measurements: Highest turbidity measurements during an ebbing tide were recorded at the OBS station nearest the spider barge at a depth of 1.5 m, where values ranged from 9.9 to 87 NTU (mean = 24.3). At this station, readings from the bottom sensor were generally less turbid at 39.9 NTU (mean = 23.2). Farther downstream from the spider barge at Station 2, highest turbidities were recorded by the bottom sensor (range = 19.3 to 70.0 NTU, mean = 30.4) as sediment had begun to settle to the lower strata of the water column. Readings from the upper sensor at Station 2 ranged from 10.6 to 53.9 NTU (mean = 20.1). Highest turbidities measured at Stations 1 and 2 (70 and 87 NTU) were on average twice that observed in ambient waters (highest reading = 36.5 NTU) (compare Figures 2 and 3). Mean ambient turbidity values (mean = 18.3 NTU) were somewhat lower than at Station 2 (OBS unit positioned within the plume, mean = 30.4 NTU). The OBS data indicated that the suspended sediment plume consisted of "pulses" of turbid water, as NTU values would rise and fall over the course of a tidal cycle. Peak turbidities were relatively short-lived. This is illustrated clearly in Figure 2 as highest turbidity levels peaked above 80 NTU before returning to ambient conditions.

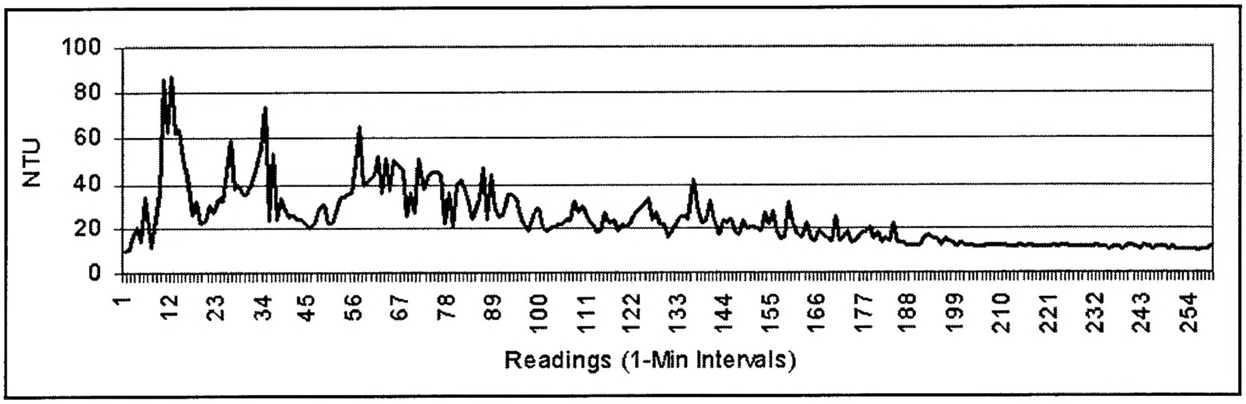

Figure 2. Measurements taken by an OBS unit (Station 1, sensor at 1.5 m) moored on the downstream side, nearest the spider barge, to measure turbidity levels (NTU) during an ebbing tidal cycle

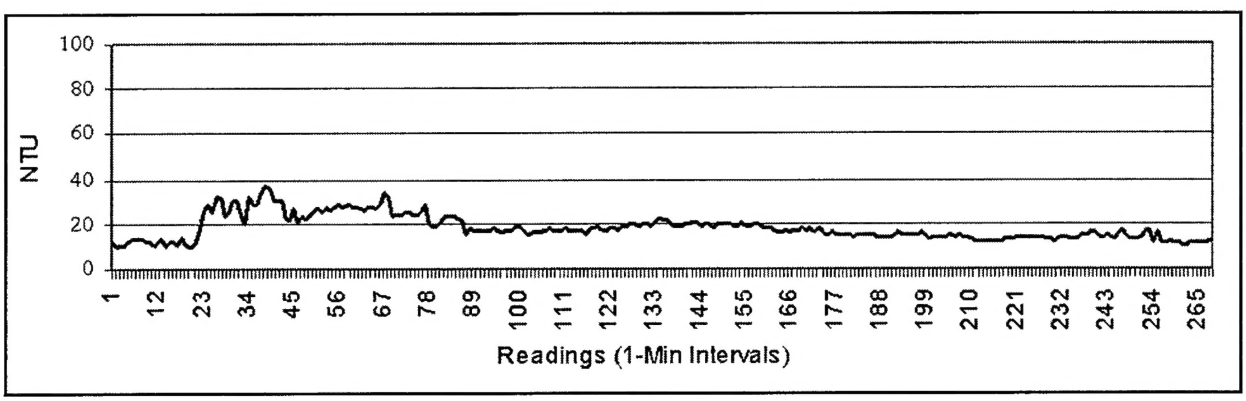

Figure 3. Measurements taken by an OBS unit (Station 3, sensor at 1.5 m) moored on the upstream side of the dredge to measure turbidity levels (NTU) during ambient conditions

Flood tide measurements: Highest overall turbidities were observed during flood tide conditions. Highest turbidity values, ranging from 13.9 to 127.7 NTU (mean = 45.3), were observed at the lower sensor (7.5 m) at Station 3, which measured upstream ambient conditions. The upper water column OBS unit (1.5 m) did not record values markedly different from those observed for ambient conditions taken during an ebbing tide (Figure 4). Highest readings (9.0-126 NTU, mean = 38.9) for the OBS units positioned within the plume occurred at Station 1 at a depth of 7.5 m. Although somewhat lower, similar readings occurred at this depth in Station 2. Mean turbidity measurements in the upper water column (1.5 m) did not differ substantially among the three stations measured; however, short-term maximum readings reached 106 NTU at Station 1, located nearest the spider barge (Figure 5). Consistent with the ebb tide data, high turbidities were relatively short-lived events as illustrated in Figure 5. Some factors contributing to the "pulsed nature" of the sediment plume include the type of dredge plant, sediment type (e.g., mud versus sand), and intermittent pauses in the production rate of the dredge.

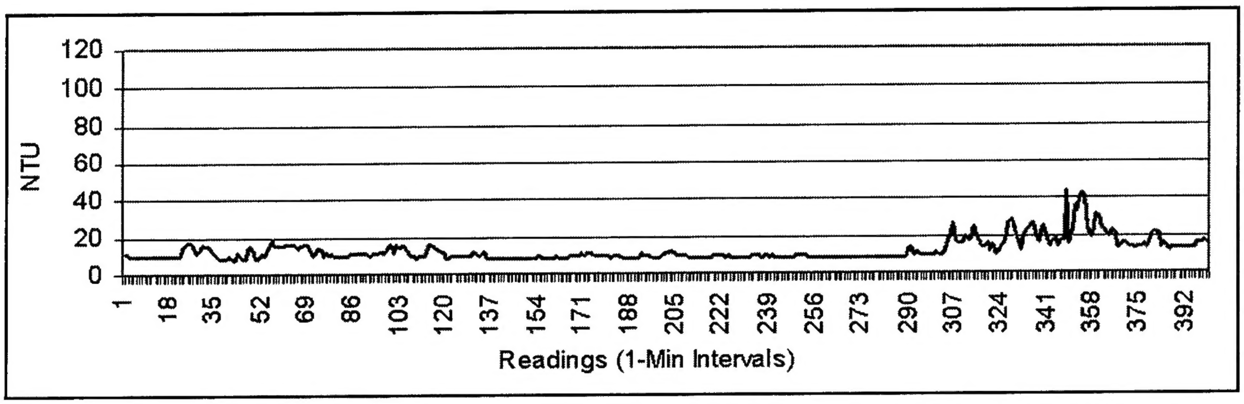

Figure 4. Measurements taken by an OBS unit (Station 3, sensor at 1.5 m) moored on the downstream side of the spider barge, to measure turbidity levels (NTU) during ambient conditions

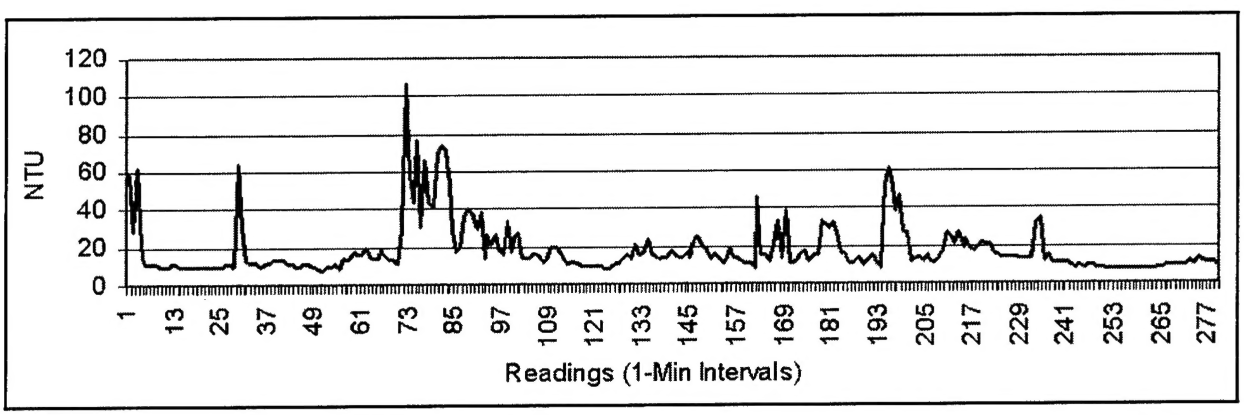

Figure 5. Measurements taken by an OBS unit (Station 1, sensor at 1.5 m) moored on the upstream side, near the spider barge, to measure turbidity levels (NTU) during a flooding tide cycle

Acoustic Doppler Current Profiler - Current Velocity. Cross-channel transects were oriented perpendicular to the long axis of the channel thalweg. Velocity magnitude in feet per second relative to the channel bottom is presented in the upper panel of each profile. Velocities have been converted to cm/sec for the following discussion. Mobile transects taken during ebb tide indicated that current velocities during midcycle ranged from 75 to 150 cm/sec across the entire river cross section. Velocities tended to decrease with increasing depth, with an indication of slower velocities less than 60 cm/sec just above the channel bottom. Velocities were generally lower over the shoal than in the main navigation channel. Downstream movement of ebbing water began in surface depths. Water velocities averaged 75 cm/sec in waters less than 3 m deep, whereas water velocities were still near zero along the channel side slope and bottom.

The flood tide survey started 3 hr into the flood tide cycle (midcycle). Water velocities at this time had reached 150 cm/sec across most of the channel proper. Slower velocities were recorded along the channel side slopes, ranging from 75 to 110 cm/sec. Lowest velocities were found over the shoals at 40 cm/sec. A current velocity magnitude profile taken at midflood cycle approximately 520 m from the dredging operation is depicted in Figure 6. Note the somewhat slower water velocity over the shoals and the western slide slope, indicated by the red pixels. Velocities in this profile were fairly uniform within the channel from surface to bottom; however, a slightly higher flow was still present along the eastern side of the channel. The ambient survey was conducted during a flooding tide. No changes in current velocity magnitude were detected in this survey compared with those observed in the previous flood tide survey during the plume tracking survey.

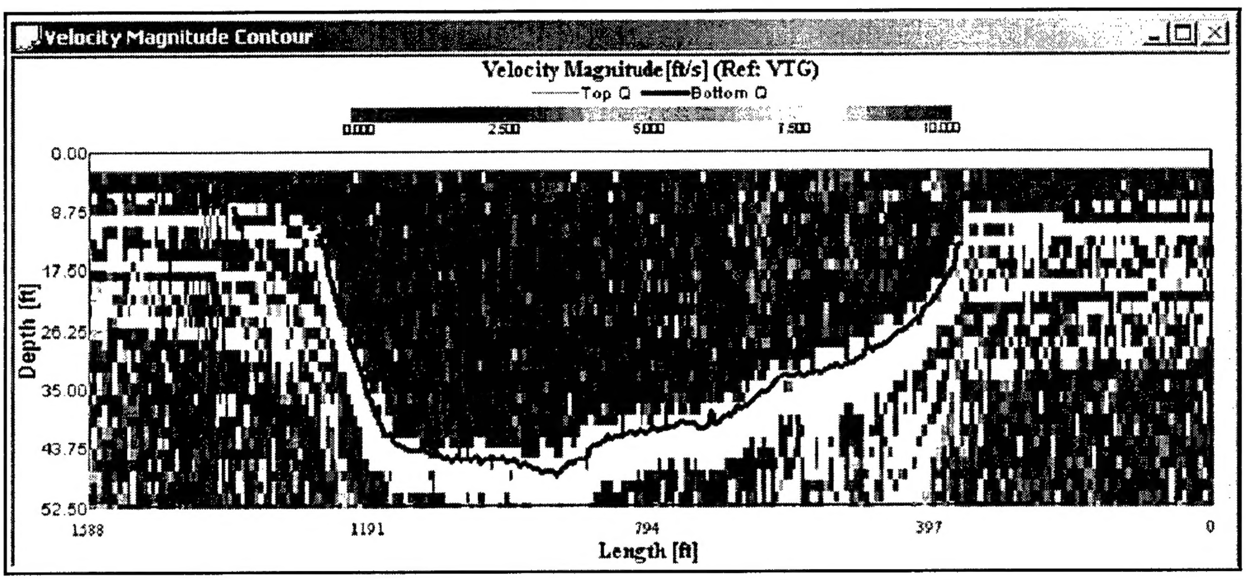

Figure 6. An example of a current velocity profile from an ADCP survey of the Cape Fear River, NC (Transect 8 was taken during a flooding tide, 520 m from the dredging operation. The left side of the echogram represents the west bank of the river.)

Sediment Plume Characterization

Ebb tide plume characteristics: A suspended sediment plume was tracked during an ebb tide survey from just south of channel marker 43 through a portion of the Keg Island Range (Figure 1). The survey began 1 hr into the tidal cycle and finished just past midcycle. Figures 7a and b show the plume signatures at 30 and 150 m from the spider barge overflow source, respectively. TSS concentrations estimated acoustically in the plume this close to the source cannot be taken as absolute values due to air bubble entrainment in the overflow discharge. Air bubbles have been shown to dissipate fairly quickly, however, and therefore should influence concentration estimates only in the area adjacent to and immediately downcurrent from the overflow barge. TSS concentration estimates ranged from 70 mg/L along the bottom and western side slope of the channel to greater than 90 mg/L within the sediment plume. The plume is best characterized as a narrow band of increased TSS initially extending throughout the water column (surface to bottom, identified in red in Figures 7a-d). TSS concentrations over the shoals ranged from 20 to 40 mg/L. These ranges were confirmed with onsite water samples, which ranged from 21 to 43 mg/L (Table 3, Stations 5, 19, 27, and 28). Figure 7c shows the plume at a distance of 300 m from the overflow point. The plume signature cross-sectional area of high TSS concentrations (>90 mg/L) has diminished in spatial extent compared with the plume signature in Figures 7a and b. The central portion of the plume and high TSS concentrations were now confined to the upper 3 m of the water column. The lower half of the plume has begun to descend toward the channel bottom extending across the channel from the east to the west side slopes. TSS concentrations ranged from 60 to 70 mg/L, except in the lower meter of the water column where values ranged from 80 to 90 mg/L. Figure 7d depicts the plume at a distance of 455 m from the source. Highest TSS concentrations there are confined to the bottom 2-3 m of the channel bottom. No evidence of plume infiltration onto the adjacent shoals was seen, as TSS values there ranged between 20 and 40 mg/L. Note that the transects depicted in Figures 7a and d run in a west-east direction and that the transects in Figures 7b and c run in an east-west direction; therefore, the shallow area in all figures is the western shoal. The transect depicted in Figure 7d was shortened due to ship traffic in the area.

Flood tide plume characteristics: A suspended sediment plume was tracked during a flooding tide from just north of channel marker 43 to just south of channel marker 45/46 in the Big Lower Range. Figures 8a and b depict a well-defined suspended sediment plume extending from surface to bottom from 10 to 215 m from the barge overflow point. Note that each of these transects was shortened on the western side of the channel due to the position of the pipeline. As with the ebb tide survey, air bubbles entrained near the discharge point probably inflated suspended sediment concentrations estimates. As seen previously, TSS values in the upper portion of the water column (1.5 to 4 m) averaged less than 30 mg/L. TSS concentrations at middepths (4-8 m) ranged between 40 and 50 mg/L. In water depths >8 m TSS values ranged from 60 to 80 mg/L. Some of the observed suspended sediments in bottom waters may represent residual plume material carried back by tidal flows, as similar patterns were seen during the ambient survey taken during flood tide conditions. Concentrations over the eastern shoal did not differ from that observed during the ambient survey. At 365 to 670 m downcurrent the plume gradually descended to deeper waters (Figures 8c and d). The plume also shifted from a west-central location within the channel to along the western side slope following a slight dogleg to the northwest in the channel. No substantive difference in suspended sediment concentration between the eastern shoal (farthest away from the plume) and the western shoal was observed. Both shoals had TSS concentration values ranging from 20 (surface

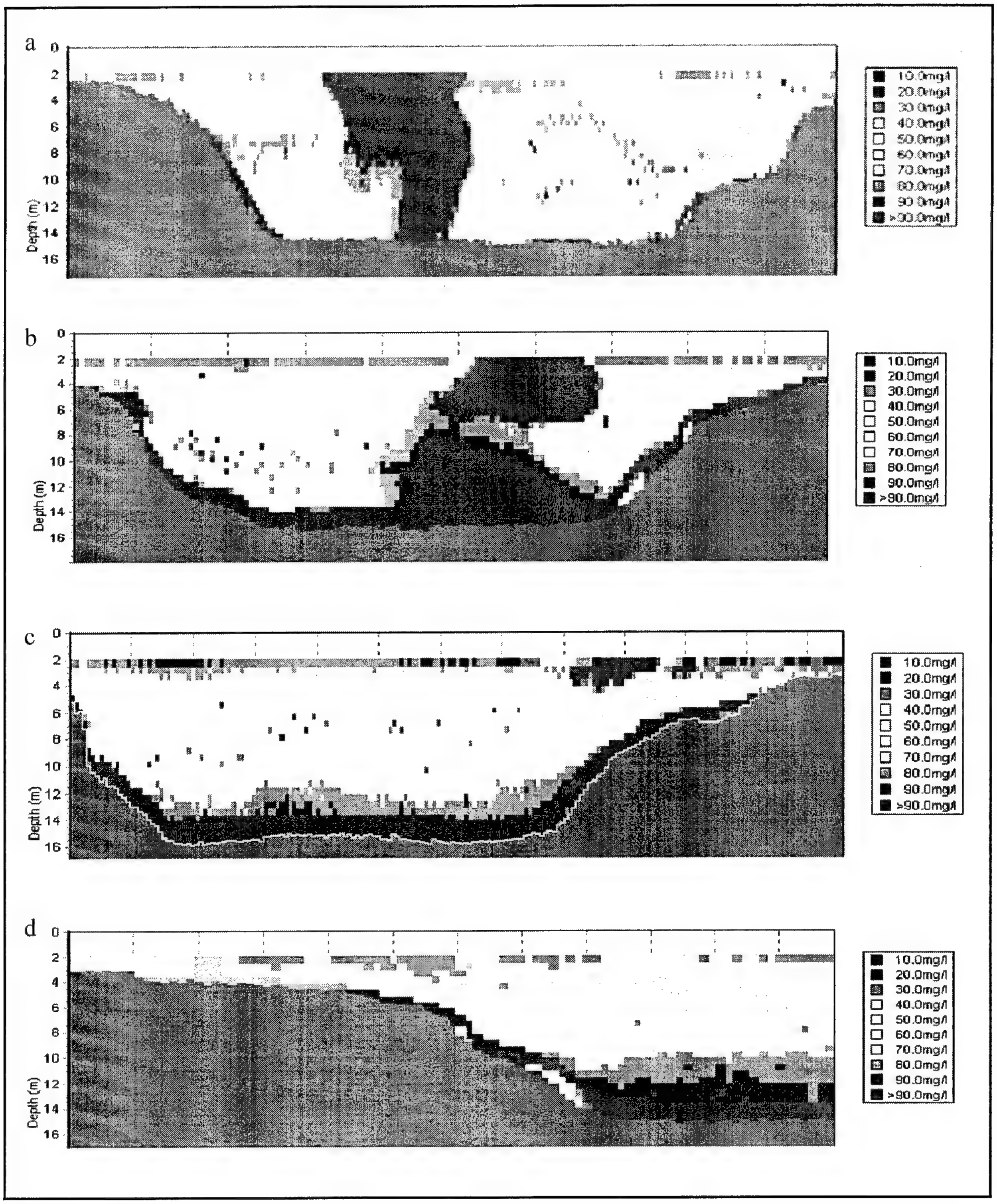

Figure 7. Selected transects depicting changes in the suspended sediment plume during the ebb tide survey, with increasing distance from the dredging operation. (Note that Transects 7a and d run in a west-east direction, while Transects 7b and c run in an east-west direction. Distances from the dredging operation are 30, 150, 300, and 500 m, respectively.)

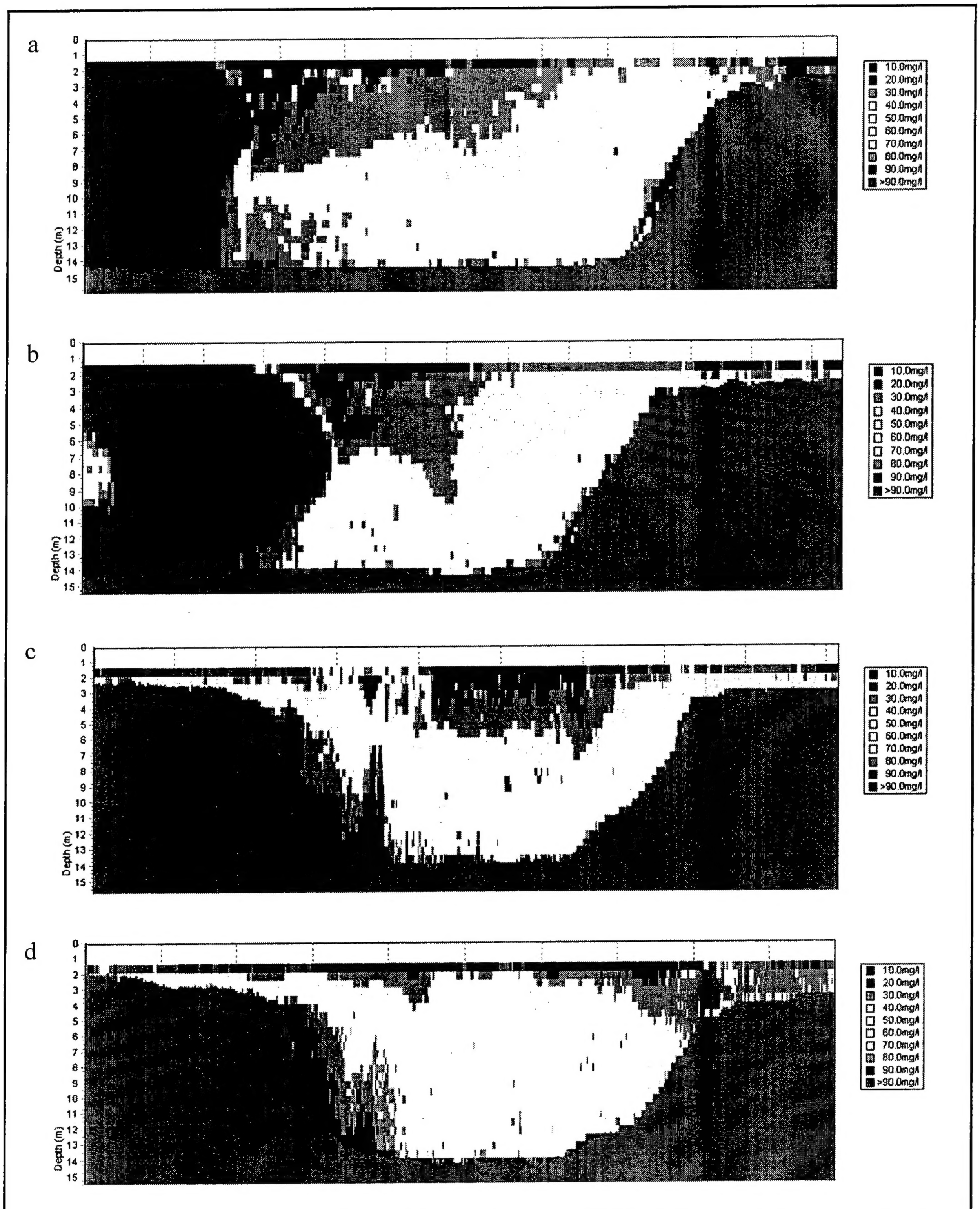

Figure 8. Selected transects depicting changes in the suspended sediment plume during the flood tide survey, with increasing distance from the dredging operation (Note that the left side of the echogram represents the west bank of the river. Distances from the dredging operation are 60, 215, 365, and 670 m, respectively.)

to midwater) to 40 (midwater to bottom water) mg/L. These ranges were confirmed with onsite water samples, which ranged from 19 to 33 mg/L (Table 3, Stations 53-56).

Ambient conditions: Total suspended sediment concentration was assessed for eight transects taken in an area opposite the direction of plume movement, that is, the downstream side of the dredging operation during a flooding tide. Suspended sediment concentrations were lowest in the upper part of the water column (<3 m) averaging less than 20 mg/L (Figure 9). From 3 to 7 m, TSS concentrations were estimated at 30 mg/L. TSS concentration ranged from 40 to 50 mg/L from 7 to approximately 10 m. The bottom stratum of the water column exhibited the greatest variation between transects. On Transects 1-5, TSS concentration had risen to 70 mg/L; however, there were some estimates that ranged from 70 to 90 mg/L just above the channel bottom. Transects 7 and 8 differed from the other transects in that the bottom 2 m in the channel had TSS concentrations equal to or greater than 90 mg/L. TSS concentrations along the shoals of the fishery nursery grounds averaged less than 20 mg/L during the ambient conditions survey.

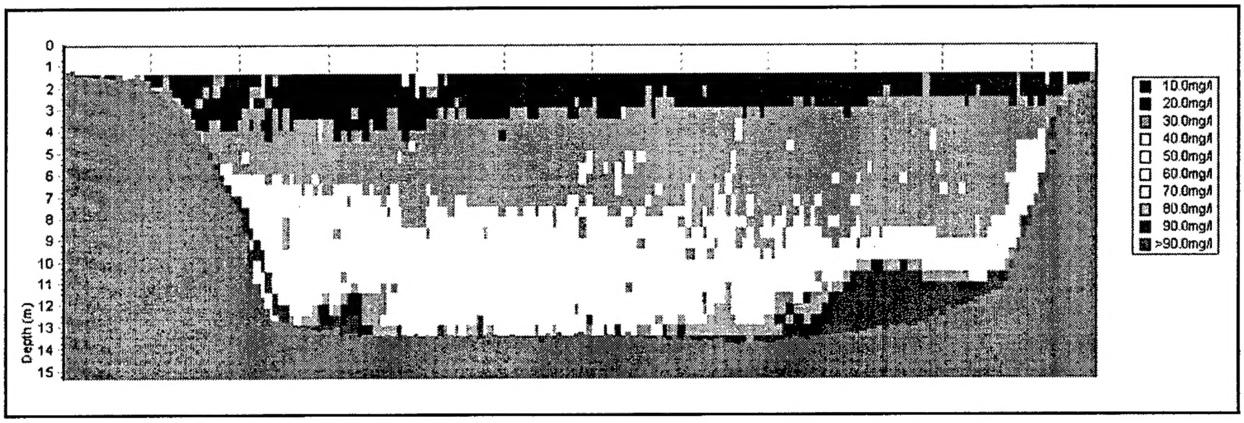

Figure 9. An example of an ADCP survey of ambient conditions in the Cape Fear River, NC (The left side of the echogram represents the west bank of the river.)

CONCLUSION: The suspended sediment plumes tracked in this study can best be characterized as relatively narrow swaths of increased TSS concentration above ambient levels. The plume near the dredging operation was located just west of the channel center during the ebb tide survey. With increasing distance from the overflow barge, approximately within 300 m, significant settling of the plume to the lower portion of the water column occurred. As settling occurred, the plume swath broadened along the bottom of the channel proper. One feature observed in the flood tide survey was that the plume moved upstream toward the western side of the channel, and at a distance of approximately 350 m (Transect 7) was found hugging the channel side slope. This may have been due to a slight dogleg in the channel configuration at the beginning of the Big Lower Range. No evidence was seen of the plume infiltrating the shoals during either the ebb or flood tide surveys. Water samples collected over the shoals during active dredging ranged from 19 to 33 mg/L compared with a maximum of 191 mg/L within the plume nearest the barge and from 60 to 80 mg/L in the plume at a distance of 300 m.

A review of relationships among turbidity, suspended sediment, and water clarity can be found in Davies-Colley and Smith (2001). In waters with a relatively homogeneous mix of suspended

sediment particle characteristics, a strong correlation generally exists between TSS concentration obtained from gravimetric analyses and turbidity levels obtained from OBS. It should be noted that to reduce potential error in comparing gravimetric and optical measures in the same system, paired measures of the same samples should be taken across a broad concentration gradient, and a regression performed on the resultant values. With this caveat, NTU values for the Cape Fear River were estimated from suspended sediment concentration values. During the flood tide survey, turbidities were less than 30 NTU for all sampling stations located over the shoals with one exception (41.3 NTU). Estimated flood NTU values (<35 NTU) over the shoals did not differ significantly from samples taken during an ebbing tide. Similar to the flood tide survey, one sampling station had a slightly higher reading of 41 NTU. This range appeared to be consistent with ambient shallow-water sample values throughout the study area.

ACKNOWLEDGEMENTS: This suspended sediment plume characterization study is a joint effort by the U.S. Army Engineer District, Wilmington, and the U.S. Army Engineer Research and Development Center, Vicksburg, MS, under the Dredging Operations and Environmental Research (DOER) Program. The authors wish to express their thanks to Mr. Frank Yelverton, Planning Division, Wilmington District, for providing logistical support for field efforts and to Mr. Wick Westmoreland and Mr. Kevin Allred, captain and mate of the Corps vessel *Sanderson.*

POINTS OF CONTACT: For additional information contact Mr. Kevin J. Reine (601-634-3436, *Kevin.J.Reine@erdc.usace.army.mil*) or Dr. Douglas G. Clarke (601-634-3770, *Douglas.G.Clarke@erdc.usace.army.mil*), or the Program Manager of the Dredging Operations and Environmental Research Program, Dr. Robert M. Engler (601-634-3624, *Robert.M.Engler@erdc.usace.army.mil*). This technical note should be cited as follows:

> Reine, K. J., Clarke, D. G., and Dickerson, C. (2002). "Acoustic characterization of suspended sediment plumes resulting from barge overflow," *DOER Technical Notes Collection* (ERDC TN-DOER-E15), U.S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/dots/doer*

REFERENCES

Clarke, D. G., and Wilber, D. H. (2000). "Assessment of potential impacts of dredging operations due to sediment resuspension," *DOER Technical Notes Collection* (ERDC TN-DOER-E9), U. S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/dots/doer*

Land, J. M., and Bray, R. N. (2000). "Acoustic measurement of suspended solids for monitoring of dredging and dredged material disposal," *Journal of Dredging Engineering* 2(3), 1-17.

Davies-Colley, R. J., and Smith, D. G. (2001). "Turbidity, suspended sediment, and water clarity: A review," *Journal of the American Water Resources Association* 37(5), 1085-1101.

Puckette, T. P. (1998). "Evaluation of dredged material plumes: Physical monitoring techniques," *DOER Technical Notes Collection* (TN DOER-E5), U. S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/dots/doer*

Wilber, D. H., and Clarke, D. G. (2001). "Biological effects of suspended sediments: A review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries," *North American Journal of Fisheries Management* 21(4), 855-875.